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SILVICULTURAL RESEARCH NOTE NO. 80

DOMINION FOREST SERVICE

Macdonald
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W.M. Robertson
Chief Silvicultural
Research Division

THE EFFECT OF THINNING UPON THE GROWTH AND YIELD

OF

ASPEN STANDS

(For Ten-Year Period After Treatment)

Project P-19

by

A. Bickerstaff

OTTAWA, CANADA
May 1946.

CONTENTS

THE EFFECT OF THINNING ON THE GROWTH AND YIELD OF ASPEN STANDS
(For Ten Year Period After Treatment)

1. INTRODUCTION

In many places aspen (poplar) is considered a weed species which invades cut-over and burned-over areas to exclude more valuable species such as pine and spruce. Hence most of the silvicultural studies (4) of the aspen cover-type have been concerned with methods of re-establishing softwood species on areas presently occupied by aspen. However, during the last few years the market for aspen has increased steadily, either as a result of the reduced supply of other species in some localities or because it is the best species available for certain products. At the Petawawa Forest Experiment Station, where the present thinning experiment was carried out, aspen has been in demand for match stock and pulpwood; at times the demand for it has exceeded that for other species. Hence the problem of managing aspen stands for the prime purpose of producing the maximum amount of good quality wood became of importance for this area.

Beginning in 1934, studies were undertaken to determine whether intermediate cutting operations would increase the yield and quality of pure aspen stands. Secondary objectives were to study the development of the species on various sites, and for those sites producing low yields or poor quality to find whether a type conversion to a coniferous species was accelerated by the intermediate cutting.

The study was carried out by means of permanent sample plots in stands ranging in age from fifteen to forty years. At present two sets of remeasurement data are available--five and ten years after treatment. This report is concerned with the effects of the cutting on the growth of the stands.

2. GENERAL DESCRIPTION OF THE AREA

The experimental area lies within the Algonquin-Laurentides section of the Great Lakes--St. Lawrence Forest Region according to the forest classification described by Halliday in 1937 (2). Originally it was an area of mixed forest with white and red pine as the dominant conifers and yellow birch and sugar maple as the dominant hardwoods. However, as a result of logging and fire, the character of many of the stands, especially the pineries, has changed considerably, so that trembling aspen (Populus tremuloides) and largetooth aspen (P. grandidentata) in association with white birch, soft maple, red oak, balsam fir, white spruce, white pine, and red pine are now occupying areas which formerly supported excellent stands of pine either in pure stands or in mixture with other species (2).

These aspen stands attain a good development on most of the sites originally occupied by other species. In Heimburger's site-type classification for the Petawawa area (3), based on ground vegetation, soil, and topography, aspen occurs in appreciable amounts on the following sites,

Good sites---Trillium, and Aralia
Medium sites---Aster-Gaultheria, Aster-Corylus, Maianthemum-Corylus, Cornus-Maianthemum.
Poor Sites---Vaccinium-Myrica.

An investigation by Sisam (9) indicated that the yield and quality of aspen appeared to be correlated with the above vegetative sites.

3. ESTABLISHMENT OF EXPERIMENT

(1) General

In the period 1934 to 1936, the experiments were established by Sisam (8), in four representative stands of young aspen. The thinnings in all cases were severe, 70 to 80 per cent of the original stand being removed, as it was expected that only one thinning would be economically feasible during the rotation. Under the conditions existing at the time it was not possible to utilize the thinnings. In each of the stands selected for treatment, two permanent sample plots consisting of a thinned plot and a control plot were established to study the effect of treatment. The stands were of different age-classes and occurred on different site-types. While the experiment has the advantage of sampling a range of representative stands, it is difficult to attribute the results obtained definitely to any specific factor or factors.

On each of the plots, all trees over 0.5 inch at breast-height were numbered. Diameter measurements were made at breast-height with a tape and recorded to the nearest hundredth of an inch. Sufficient height measurements were taken at each remeasurement to permit the preparation of height-diameter curves for each species; heights were measured with an Abney hand-level and recorded to the nearest foot. Volumes were computed by diameter-classes using the average diameter of the diameter-class in conjunction with the heights obtained from the height-diameter curves. (See References 1 and 4 for volume tables used.)

Each plot has been remeasured twice since treatment, but for purposes of brevity only the data from the last remeasurement are considered herein. For three of the four pairs of plots subsequently described, the data represent growth for a ten-year period; for the other pair of plots (Nos. 153 and 154 in Stand D) the remeasurement interval is only nine years.

2) Description of the Stands Before Treatment

A general summary of the stands before treatment is given in Table 1. Values in the table were obtained by averaging the two sample plots contained in each stand.

TABLE 1

DESCRIPTION OF STANDS BEFORE TREATMENT

	Stand			
	A	B	C	D
Age (years)	25	22	40	17
Site	As-Ga	Ar	As-Cor.	Co-Ma
Soil Moisture	very dry	moist	dry	moist
Stems per acre	2500	1580	730	2710
Av. Diameter (inches)	2.5	3.3	4.8	1.5
Av. Height (feet)	30	41	57	17
Total Volume (t.c.f.p.a.)	1600	2180	2800	480
Control Plot	138	140	151	153
Thinned "	137	139	150	154

Trembling aspen and large-toothed aspen make up about 90 per cent of the number of trees in these stands, with the remainder composed chiefly of white birch, soft maple, red oak, and minor amounts of basswood, black ash, white pine, red pine, white spruce, and balsam fir. For purposes of comparison the growth of all species is grouped together.

A more detailed description of the stands is given in Appendix A, where a comparison is made of the control plots and thinned plots before treatment. It will be noted in the comparison that definite size classes or definite groups of trees are compared as well as the average or total figures for each plot. This is essential if a true picture of the comparability of the plots is to be obtained; the acceptance of a total or average figure as the basis on which to compare two plots can lead to very erroneous conclusions unless considerable discretion is used in the interpretation of the figures. For example, consider Plots 137 and 138 in Stand A: in total number of stems per acre, Plot 138 contains 600 more trees than Plot 137, but the breakdown of this figure indicates that in number of trees over 2.0 inches in diameter the stands are identical; for average diameter of the entire plot, plot 138 was 0.15 inch smaller, but on the basis of the 200 largest trees per acre in each plot, it was 0.20 inch larger than Plot 137; in the case of the average height, the over-all averages differ by 3.0 feet yet when compared by similar size groups the average heights are almost the same. Plot 138 (control) has a slightly greater volume as a result of having a greater number of trees per acre. These two plots are about as similar as it is possible to attain in natural stands, yet the gross figures seem to indicate that they are quite different in character.

The comparability of the other pairs of plots before treatment may be mentioned briefly. In Stand B the major difference between the two plots is in the volume per acre, with the plot which was thinned having a definite advantage over the unthinned plot. For Stand C, the thinned plot (150) averaged about seven feet less in height than the control and contained considerably less volume. The plots in Stand D were very similar in all respects.

(3) Thinning Operation

A summary of the thinning operation is given in Table 2, while a more detailed description of the plots is given in Appendix B.

TABLE 2

THINNING OPERATION

Removed by Thinning	Percentage of Original Stand			
	A	B	C	D
Trees per acre (over 0.5 inch D.B.H.)	81	81	73	70
Total volume per acre	63	60	53	46
Merch. " " " (to 3.5 inch top)	42	49	45	0
Stand after Thinning	A	B	C	D
Number of trees per acre	427	263	212	788
Total volume per acre (cubic feet)	573	959	1177	244
Merch. " " " " "	172	676	955	6

The thinning in all cases was severe, 70 to 81 per cent of the total number of trees per acre and 46 to 63 per cent of the total volume of the stands being removed by the operation.

Dominant and co-dominant trees of good form were favoured in the thinning; all defective and most of the intermediate and suppressed trees were removed, and, in addition, as many of the dominant and co-dominants as were required to maintain an approximately equal spacing.

The thinnings from the plots were not utilized, and no estimate of the net or gross cost of the operation is available. Trees were left where they fell and the tops lopped and scattered. The merchantable volume (to a 3.5 inch top) per acre removed was:

Stand A - 1.3 cunits

Stand B - 6.5 "

Stand C - 7.9 " (1 cunit equals 100 cubic feet)

Stand D - 0.0 "

It is apparent that only in Stands B and C is there any possibility that the thinning operation could have realized an immediate profit had a market been available for the products.

The immediate effect of thinning upon the average diameter of the stands may be noted at this point (see Appendix B for details). Any thinning which removes a majority of trees from the lower diameter and height classes of the stand will raise the average diameter and height of the stand merely by changing the diameter distribution within the stand. No improvement in the stand has taken place by virtue of this apparent increase in size; indeed, the stand usually contains fewer larger trees after the thinning than before, since most thinnings remove a few dominant and co-dominant trees to maintain spacing. For example, in Plot 137 the average diameter of the two hundred largest trees per acre dropped from 4.2 to 3.9 inches as a result of the thinning, while the average diameter of the entire stand increased from 2.6 to 3.4 inches. A similar condition exists for the other thinned plots considered in this experiment.

4. ANALYSIS OF RESULTS

An ideal situation exists when it is possible from an analysis of the field data to say that the treatment accorded was a definite success or a definite failure. With thinning experiments it is rarely possible to arrive at such ideal conclusions, especially before the end of the rotation, unless the criterion of success or failure is clearly defined; the criterion may be biological or financial.

The biological and financial success are two very different considerations but it would seem logical to determine first whether a thinning is a biological success, and then determine whether such a degree of success is commensurate with the cost involved. In the present instance, the biological success or failure is considered in some detail while the financial aspect is dealt with only in a general manner, since it is very difficult to assess until the trees are harvested.

The effect of the thinning on both the individual and per acre growth is described below.

(1) Diameter Growth

Diameter growth may be assessed in several ways. Comparisons on the basis of the average diameter of the entire stand are practically meaningless since e average diameter so determined fluctuates greatly with ingrowth and mor- lity. If a single average value for the entire stand is to be used, sat- factory results are obtained by comparing the growth of a specified number the largest trees per acre in the stand; the 200 largest trees per acre is convenient number since this is roughly the number of trees that may be ex- cted in the final stand at maturity. While this figure may be quite useful general comparisons, it is often of interest for silvicultural purposes to mpare the growth of the different diameter classes that existed on the area the time of treatment; the growth for the diameter classes is most ac- urately obtained by averaging the direct measurements.

In Table 3, the growth of the 200 largest trees per acre for the en-year period following thinning is shown for the four stands, under both ninned and unthinned conditions. In Table 4, the growth of each plot is iven by diameter classes; tabular values have been smoothed off by curving.

TABLE 3

DIAMETER INCREMENT OF 200 LARGEST TREES PER ACRE

FOR

TEN-YEAR PERIOD FOLLOWING THINNING

	Average D.B.H. (inches) Initial	Final	Average annual increment (inches)
tand A			
Thinned	3.90	6.00	0.21
Control	4.40	6.00	0.16
Stimulation by thinning			0.05 or 31 percent
tand B			
Thinned	5.35	7.95	0.26
Control	5.50	7.50	0.20
Stimulation by thinning			0.06 or 33 percent
tand C			
Thinned	6.05	7.90	0.18
Control	7.05	8.35	0.13
Stimulation by thinning			0.05 or 38 percent
tand D*			
Thinned	2.65	4.40	0.19
Control	2.60	4.20	0.18
Stimulation by thinning			0.01 or 6 percent

* Stand D--remeasurement for 9-year period.

On the above basis of comparison, three of the stands (A, B, and C) benefited materially by the thinning; these were the stands in which competition between the larger trees was severe in the original stand. The youngest stand (D) showed little response to the treatment; in this case it is doubtful whether serious competition existed between the dominant trees at the time of thinning, with the result that such trees derived but little benefit from the opening up of the stand. It should be noted that although growth was stimulated to a greater or lesser degree on all of the plots, actually the average diameter of the 200 largest trees per acre on the thinned plots differed only slightly from the average diameter of similar trees on the controls. Thus for this type of thinning, which removes some of the larger trees, it will require about ten years after treatment before the stimulation in growth is sufficient to offset the initial reduction in the average size of the largest trees which is inherent in the thinning method. (See Chart 1).

TABLE 4

DIAMETER INCREMENT BY DIAMETER CLASSES

FOR

10 - YEAR PERIOD FOLLOWING THINNING

Initial D.B.H. (inches)	Average Annual Increment - Inches											
	Stand A			Stand B			Stand C			Stand D		
	Control	Thinned	Diff.	Control	Thinned	Diff.	Control	Thinned	Diff.	Control	Thinned	Diff.
1.0	-	-	-	-	-	-	-	-	-	.04	.08	.04
2.0	.05	.09	.04	.03	-	-	-	-	-	.11	.13	.02
3.0	.09	.15	.06	.07	.15	.08	-	-	-	.17	.17	.00
4.0	.14	.20	.06	.14	.20	.06	.06	.14	.08	-	-	-
5.0	.18	.24	.06	.20	.26	.06	.08	.19	.11	-	-	-
6.0	-	-	-	-	-	-	.12	.19	.07	-	-	-
7.0	-	-	-	-	-	-	.16	.20	.04	-	-	-
8.0	-	-	-	-	-	-	.18	.20	.02	-	-	-
Average (unweighted)	.12	.17	.06	.11	.20	.06	.12	.18	.06	.11	.13	.02

From Table 4, it is apparent that the diameter growth of all size classes was stimulated to some extent by the thinning. The stimulation or difference in growth between trees of similar size was least in Stand D, the youngest stand. Three of the four stands (B, C, and D) show that there was a probable tendency for the growth stimulation to be greater in the smaller size classes than in the larger; in otherwords, the smaller trees apparently derived more benefit from the thinning than did the larger trees.

2. Height Growth

The average annual height growth for the stands under both thinned and unthinned conditions is shown in Table 5. This table was prepared by using the diameter increments in conjunction with the height-diameter curves for the Plots, (Chart 2) and then plotting the height increments over the original heights obtained from the curves to read off the average height increment for each of the ten-foot height classes which were on the plots at the beginning of the period. For example, in Plot 137, a tree which has an average diameter of 4.0 inches and a height of 41.3 feet (from height-diameter curve at establishment) grew during the period to 6.0 inches and had a height of 54.0 feet (from height-diameter curve for end of period); thus a tree which was 41.3 feet in height grew 12.7 feet during the period; by plotting height increments over initial heights so found, curves may be drawn so that the height increment for any desired height class may be read off. Such values are not nearly as reliable as the data obtained for diameter increment by direct measurement since they depend primarily upon the degree of correlation existing between diameter and height. However they do indicate in a general way the trends in growth on the plots.

TABLE 5

AVERAGE ANNUAL HEIGHT INCREMENT BY HEIGHT CLASSES

FOR

10 - YEAR PERIOD FOLLOWING THINNING

Initial Height (feet)	Average Annual Increment											
	Stand A			Stand B			Stand C			Stand D		
	C	T	D	C	T	D	C	T	D	C	T	D
10	-	-	-	-	-	-	-	-	-	0.9	1.1	0.2
20	-	-	-	-	-	-	-	-	-	1.2	1.1	0.1
30	1.1	1.0	0.1	0.7	1.1	0.4	-	-	-	1.3	1.0	0.3
40	1.4	1.3	0.1	1.1	1.7	0.6	-	-	-	-	-	-
50	1.5	1.1	0.4	1.0	1.7	0.7	0.7	0.9	0.2	-	-	-
60	-	-	-	-	-	-	0.6	0.9	0.3	-	-	-
70	-	-	-	-	-	-	0.5	0.7	0.2	-	-	-
Average (unweighted)	1.3	1.1	0.2	0.9	1.5	0.6	0.6	0.8	0.2	1.1	1.1	0.2

C - Control T - Thinned D - Difference

The average annual height growth for each of the plots was between 0.9 and 1.7 feet per year. The height growth did not appear to be affected by the thinning; in stands B and C the thinned plots had a slightly better growth than the control plots; in stand A the reverse was true, while in stand C the growth was about equal. On almost all the plots it was noted that the height growth of the intermediate size classes was almost equal to, or greater than, the growth of the largest trees; it is considered that this peculiarity is probably the result of inaccuracies inherent in measuring the height of large-crowned species with a hypsometer.

The average height growth of the two hundred largest trees per acre in each of the plots did not exhibit any material difference between the thinned and unthinned condition.

3. Volume Growth

Volume growth can be expressed in so many ways in comparing thinned and unthinned stands that it is well to define clearly the meanings of the various terms used in any specific comparison. In the present instance, the following terms are used with the meanings indicated:

Initial volume -- Living volume of stand at beginning of experiment (before thinning).

Final volume -- Living volume, 10 years after thinning, of those trees which were present in the stand at the beginning of the experiment.

Net increment -- Difference between final and initial living volume. If the final volume is less than the initial volume, the net increment will be negative in value.

New growth -- New trees which have entered the stand in the ten-year period.

Mortality -- Volume of all trees which have died during the 10-year period.

Thinnings -- Volume of trees removed by the thinning operation. When thinnings are subtracted from the initial volume, the volume of the stand immediately after thinning is obtained.

Gross increment -- Net increment plus new growth, mortality and thinnings. It is the total amount of wood manufactured by the stand in the ten-year period.

Useful increment - For untreated stand is equal to the net increment; for thinned stands it is the difference between the volume immediately after thinning and the final volume.

For purposes of comparison, net, gross and useful increment are the most important of the terms mentioned. Net and gross increment are standard terms which are self-explanatory; "useful" increment is a term which has been introduced to show the increment added to the trees which are living at the end of the period. For unthinned stands this increment is equivalent to the net increment as defined above, but for thinned stands it is the difference between the volume immediately <u>after</u> thinning and the final volume. Thus to find the useful increment from data arranged as in the accompanying tables, the amount removed by thinning must be deducted from the initial volume and the result subtracted from the final volume; this is equivalent in value to adding the amount removed in thinning to the net increment for the period.

Comparisons of the above nature may be made in terms of total or merchantable volume for the whole stand, as shown in Tables 6 and 7, or for the dominant part of the stand, as shown in Table 8.

The dominant part of a stand is arbitrarily considered as the 200 largest trees per acre; because of mortality and differences in growth, the 200 largest trees per acre at different periods in the life of the stand are not necessarily composed of the same individual trees. In comparisons of the dominant part of the stand, only the net and useful increments are considered.

TABLE 6

VOLUME AND VOLUME INCREMENT PER ACRE
FOR 10-YEAR PERIOD FOLLOWING THINNING

(Total Volume All Trees Over 0.5 inches D.B.H.)

	Stand A		Stand B		Stand C		Stand D(x)	
	Cont.	Thin.	Cont.	Thin.	Cont.	Thin.	Cont.	Thin.
Initial	16.9	15.7	19.4	24.3	30.5	25.1	5.1	4.5
Final	28.9	15.5	33.4	25.3	30.1	16.7	13.3	7.4
Net Inc.	12.0	- 0.2	14.0	1.0	0.4	-8.4	-8.2	2.9
New Growth	-	0.6	-	1.3	0.1	0.3	0.4	0.4
Mortality	4.2	0.4	5.9	1.5	9.6	3.7	2.3	1.1
Thinnings	-	10.0	-	14.6	-	13.3	-	2.0
Gr. Incr.	16.2	10.8	19.9	18.4	9.3	8.9	10.9	6.4
Useful Inc.	12.0	9.8	14.0	15.6	-0.4	4.9	8.2	4.9

(x) Stand D - Increment for 9-year period only.

TABLE 7

VOLUME AND VOLUME INCREMENT PER ACRE
FOR 10-YEAR PERIOD FOLLOWING THINNING

(Merchantable Volume All Trees Over 3.5 inches D.B.H.)

	Stand A Cont.	Stand A Thin.	Stand B Cont.	Stand B Thin.	Stand C Cont.	Stand C Thin.	Stand D (x) Cont.	Stand D (x) Thin.
nitial	3.4	3.0	9.1	13.3	22.0	17.5	-	0.1
inal	16.7	11.0	26.0	21.3	26.5	15.1	3.1	2.5
et Inc.	13.3	8.0	16.9	8.0	4.5	2.4	3.1	2.4
ew Growth	-	-	-	-	-	-	-	-
ortality	0.5	0.2	1.2	1.2	6.9	3.1	0.1	0.1
hinnings	-	1.3	-	6.5	-	7.8	-	-
ross Inc.	13.8	9.5	18.1	15.7	11.4	8.5	3.2	2.5
seful Inc.	13.3	9.3	16.9	14.5	4.5	5.4	3.1	2.4

(x) Stand D - 9-year period only.

TABLE 8

VOLUME AND VOLUME INCREMENT OF 200 LARGEST TREES PER ACRE
FOR
10-YEAR PERIOD FOLLOWING THINNING

	Stand A		Stand B		Stand C		Stand D (x)	
	Cont.	Thin.	Cont.	Thin.	Cont.	Thin.	Cont.	Thin.
	Total Volume (over 0.5 in. D.B.H.) - Cunits							
Initial	4.9	4.5	9.4	12.0	19.0	14.3	1.3	1.4
Final	10.6	10.6	19.1	24.3	24.6	16.7	3.9	4.2
Net Incr.	5.7	6.1	9.7	12.3	5.6	2.4	2.6	2.8
Thinnings	-	0.2	-	3.2	-	2.5	-	0.1
	Merchantable Volume (over 3.5 in. D.B.H.) - Cunits							
Initial	2.6	2.5	7.2	9.4	15.1	12.0	0	0
Final	8.8	8.0	17.5	21.1	22.2	15.0	2.5	2.3
Net Incr.	6.2	5.5	10.3	11.7	7.1	3.0	2.5	2.3
Thinnings	-	0.7	-	2.7	-	2.4	-	0

(x)Stand D - 9-years growth only.

The net increment of the stands in total volume (Table 6) indicates that only two of the thinned stands, B and D, put on enough increment to compensate for the volume lost in thinning; i.e. the final volume was greater than the initial volume, or the increment was positive in sign. In no case is the increment of the thinned stand greater than the net increment of the corresponding unthinned stand. In terms of merchantable volume (Table 7) a similar condition exists, except that three instead of two thinned stands have a positive net increment. When only the increment of the 200 largest trees per acre is considered, (Table 8) all thinned stands show a positive net increment, with two of the thinned stands having a greater net increment than the corresponding control stands. In general, it would appear that aspen stands when subjected to a heavy thinning will require about ten years before the total and merchantable volume of the entire stand will equal that originally on the area before thinning. In other words ten year's growth will be sacrificed to effect a redistribution of increment on a smaller number of larger trees.

The increment on the smaller number of trees in the thinned stands, and which for want of a better name was designated as "useful" increment, was also generally less on the thinned plots than on the controls; if only the largest trees are considered, there is little difference in the useful increment. The per tree increment will of course be much greater in the thinned stands.

The gross increment is an index of the wood-producing capacity of the areas under the growing conditions existing on them during the period, and while the figure may be of little economic significance it is useful from a purely biological point of view. In the present experiment, the gross increment of the thinned plots was in all cases less than that of the control plots in terms of both total and merchantable volume. The reason for this is fairly obvious. In the thinned stands a high proportion of the initial volume was removed in the thinning and can therefore be considered as a block of capital that was dissipated and upon which no interest or increment was earned. The residual capital, or number of trees, did not accumulate interest or increment at a sufficiently accelerated rate to compensate for that increment which would have been added to those trees removed in the thinning. However, should the present rate of increase be continued, it is quite possible that the gross increment for, say, a twenty-year period following thinning will be greater for thinned stands than for unthinned stands.

As long as the increment for thinned stands is not materially less than that for unthinned stands, the prime purpose of the thinning will have been served, i.e., a concentration of increment on a relatively small number of trees will have been effected. If the per acre increment of thinned and unthinned stands is the same, the increment per tree of the thinned stand will be greater than that of the unthinned stand in inverse proportion to the number of trees contained by the two stands. In this experiment, the per acre increment of thinned and unthinned stands did not differ appreciably.

TABLE 9

INCREMENT PER TREE - TOTAL CUBIC FEET
(10-YEAR PERIOD FOLLOWING THINNING)

	Stand A		Stand B		Stand C		Stand D[2]	
eatment	Number of Trees[1]	Incr. per Tree	Number of Trees	Incr. per Tree	Number of Trees	Incr. per Tree	Number of Trees	Incr. per Tree
ontrol	1357	1.19	898	2.22	382	2.43	1719	0.63
inned	407	2.51	234	7.31	148	5.81	619	0.97
atio ninned-Control	0.3	2.1	0.3	3.3	0.4	2.4	0.4	1.5

1 - Living at end of period

2 - Stand D. 9-year period only

As mentioned, the average increment per tree is much greater in he thinned stands, provided that the per acre increment of the thinned and nthinned stands is similar. The average increment per tree of those trees iving at the end of the ten-year period is shown in Table 9. The per tree ncrement of the thinned stands was from 1.5 to 3.3 times as great as the er tree increment of the untreated stands. Such a condition obtains for wo reasons: first, trees in the thinned stand were actually growing faster han those in the unthinned areas; secondly, there are many more slow-growing maller trees in the unthinned stand, which tend to reduce the average appreciably. A graphic comparison of per tree and per acre growth is made in hart 3. When a corresponding group of the largest trees in each stand is onsidered, there is little difference in the individual growth (see Table 3).

1. <u>New Growth</u>

When aspen stands are thinned a profuse secondary stand originating from root suckers, advance growth, and new seedlings rapidly becomes established beneath the trees of the older age-class; this new stand after ten years comprised from 54 to 79 per cent of the total number of trees in the stand. In contrast, the new growth in untreated aspen stands made up only from 2 to 26 per cent of the total number of trees. In both cases new growth comprises ... of the total volume (see Table 10).

TABLE 10

NEW GROWTH PER ACRE

(Over 0.5 in. D.B.H. entering stands in ten-year period following treatment)

Stand and Treatment		Stems: Number	Stems: Per cent Total Stand	Volume: Cunits	Volume: Per cent Total Stand	Composition on Basis of Number: Aspen	Composition on Basis of Number: Other Hdwds.	Composition on Basis of Number: Conifers
A	Control	40	2.8	-	-	-	100	-
	Thinned	708	63.8	0.6	3.7	69	31	-
B	Control	22	2.4	-	-	-	100	-
	Thinned	910	79.4	1.3	4.9	28	72	-
C	Control	86	18.0	0.1	0.3	-	93	7
	Thinned	325	66.0	0.3	0.8	24	70	6
D	Control	630	25.9	0.4	4.3	2	96	2
	Thinned	730	54.1	0.4	5.1	-	94	6

The species composition of the new growth was interesting in that the predominant species were not aspen. In all of the thinned stands, except stand A, aspen comprised less than 30 per cent of the new growth; the remaining 70 per cent was composed chiefly of other hardwoods with soft maple being the most commonly represented species. In untreated stands, the new growth was almost exclusively species other than aspen. A peculiar condition exists in stand D, where the thinned stand produced no new growth of aspen and the unthinned stand had almost as many new trees (mostly soft maple) enter it as did the thinned stand. At the present time no explanation of this peculiarity is available, but since the site occupied by this stand, and also by stand C, appears to be better suited to the production of mixed or coniferous species, a special study is being undertaken to determine why aspen did not reproduce following cutting, since this question will be important in effecting a type conversion.

In summary, the new growth in thinned stands represents after ten years the major portion of the number of trees on the area but a relatively small proportion of the total volume, and the composition of the new growth is predominantly species other than aspen. In unthinned stands there is also a variable influx of species other than those in the original stand, but the amount of this growth is considerably less in most cases than that entering thinned stands.

5. Mortality

Mortality both in number of trees and in volume per acre is less in thinned stands than in unthinned stands. (Table 11). This is the result which might be expected since the thinnings removed those trees which had the poorest chances of survival. From the table it may be seen that the mortality on unthinned plots was from 9 to 70 times the number of trees and from 2 to 4 times the volume of that in the thinned stands.

TABLE 11

MORTALITY PER ACRE

(In trees over 0.5 in. D.B.H. for 10-year period following treatment)

Stand and Treatment		Stems			Total Volume		
		Number	Per cent of Original		Cunits	Per cent of Original	
			Before Thinning	After Thinning		Before Thinning	After Thinning
A	Control	1405	68.9	68.9	4.2	25.9	25.9
	Thinned	20	0.1	4.7	0.4	2.5	7.0
B	Control	878	67.3	67.3	5.9	30.4	30.4
	Thinned	29	0.2	11.0	1.5	6.2	15.5
C	Control	322	45.7	45.7	9.6	31.4	31.4
	Thinned	64	8.2	30.2	3.7	14.7	31.4
D	Control	1254	42.2	42.2	2.3	45.1	45.1
	Thinned	169	6.4	21.4	1.1	24.5	44.1

Mortality for a given period may conveniently be expressed as a percentage of the stand at the beginning of the period; for the thinned stands two values are given in the table, one as a percentage of the stand before thinning and the other as a percentage after thinning. The ten-year mortality expressed in terms of number of trees was, for the thinned stands, less than 8 per cent of the original number of trees or from 5 to 30 per cent of the number on the area immediately after thinning; for the unthinned stands the mortality was from 42 to 69 per cent for the same period. A similar condition exists when the mortality is expressed in total volume rather than as number of trees. (Table 11). It is obvious that thinning materially reduces the natural mortality, but unless the trees removed by the thinning are utilized there is no economic advantage merely by virtue of the reduced mortality. The species composition of the mortality was almost exclusively aspen.

Mortality may be used to evaluate the intensity of the thinning operation. If the amount removed in the thinning was equal only to the mortality which might normally be expected to occur in ten years under unthinned conditions, the thinning would not be worth while unless it were made at a profit. In the summary below, the ratios of the amount removed in thinning over the mortality which occurred in the ten-year period in the untreated stand are shown.

Ratios of Amounts Removed to Mortality

	Number of Trees	Total Volume
Stand A	1.25	2.38
Stand B	1.27	2.49
Stand C	1.75	1.38
Stand D	1.48	0.88

In so far as number of trees is concerned, the thinnings were fairly consistent in removing about one and a half times the number that would normally die in the next ten years had the stands not been thinned. In terms of volume there was little consistency: the volume removed varied from an amount equal to the ten-year mortality to an amount two and a half times the actual mortality which occurred in the unthinned stands. The discrepancy between the ratios for number of trees and volume may be accounted for by the large number of fairly large trees which died as a result of pathological agents.

On the basis of such a comparison the thinnings do not appear to be unduly severe since the natural mortality was high. However, in the untreated stands the natural thinning from mortality took place over a ten-year period whereas the planned thinning was made at one time and resulted in a considerable shock to the stands accompanied by considerable damage from secondary factors (see Section 8--Pathological Conditions). It would seem therefore that thinning possibilities in aspen stands are definitely limited: if the thinning only anticipates natural mortality for a ten-year period, little stimulation of growth can be expected, and, if more than the anticipated natural mortality is removed, the shock to the stands may be disastrous.

6. Number of Stems

In Table 12 the number of stems per acre over 0.5 in. D.B.H. are summarized under various headings. It is apparent that the thinning made in Stand C was much too severe; only 212 trees per acre were left after the thinning and of this number 64 died during the following ten years, to leave a main stand of only 148 trees per acre at an age of 50 years.

In all of the thinned stands the number of new trees entering the stand was greater than the number of trees which died during the same period.

TABLE 12

NUMBER OF TREES PER ACRE
(over 0.5 inches D.B.H.)

	Stand A		Stand B		Stand C		Stand D	
	Cont.	Thin.	Cont.	Thin.	Cont.	Thin.	Cont.	Thin.
Before Thinning	2762	2189	1776	1379	704	778	2973	2651
Thinnings	-	1762	-	1116	-	566	-	1863
After Thinning	2762	427	1776	263	704	212	2973	788
Mortality (10 years)	1405	20	878	29	322	64	1254	169
Main Stand (After 10 years)	1357	407	898	234	382	148	1719	619
New Trees	40	708	22	910	86	325	630	730
Total Stand (After 10 Years)	1397	1115	920	1144	468	473	2349	1349

7. Stand Density

Of the many indices used to represent stand density, the most useful appear to be those which are based on the relationship between average diameter and number of trees per acre: with such an index it is possible to see whether stands are increasing or decreasing in relative density. In the present analysis the stand density criteria devised by Mulloy (6) have been used. The stand density indices of the various plots are shown in Table 13.

TABLE 13

STAND DENSITY INDEX

	Stand A		Stand B		Stand C		Stand D	
	Cont.	Thin.	Cont.	Thin.	Cont.	Thin.	Cont.	Thin.
Before Thinning	304	256	245	266	224	232	140	124
After Thinning	304	76	245	65	224	91	140	54
After 10 Years								
Main Stand	310	143	278	151	196	107	202	109
Secondary Stand	-	18	-	23	2	8	16	16
Total	310	161	278	174	198	115	218	125

The thinning reduced the densities to approximately one half to one quarter of the original densities, to leave the thinned stands with stand density indices (S.D.I.) ranging from 54 to 91. The control plots had densities from 140 to 304 stand density units.

Ten years after the thinning the density of the thinned plots had approximately doubled, even when the new growth is excluded from consideration; when the new growth is added the densities are further increased by from 8 to 23 units. The density of the unthinned plots also increased, but not nearly to the same extent as the thinned plots. On further analysis it was found that there was a definite curvilinear relationship between rate of increase in S.D.I. and initial S.D.I. with those of a low density increasing rapidly while those with a high initial S.D.I. either increased very slowly, remained stationary, or decreased. The maximum density attained by aspen stands appeared to be in the neighborhood of 310 stand density units. While there is very probably a relationship existing between stand density index and volume increment, there are insufficient data available from the experiment to isolate the effects of the numerous variables so as to arrive at any definite conclusions with respect to the stand density index.

. Pathological Conditions

A study to assess the incidence of disease and other injuries in he aspen stands considered in this report was conducted by Dr. C.G. Riley nd Dr. A.J. Skolko of the Division of Botany and Plant Pathology, Dominion epartment of Agriculture, in 1939 and 1940, five years after the stands ere thinned. Since their report (7) has not been published a summary is iven here by the kind permission of the authors.

Hypoxylon canker and sun-scald are the most important of the everal kinds of diseases and other defects encountered on the plots. The elative incidence of these defects is shown in Table 14.

TABLE 14

PATHOLOGICAL CONDITION OF PLOTS FIVE YEARS AFTER THINNING

Stand and Treatment		Number of Trees Examined	Per cent Affected	
			Hypoxylon Canker	Sun-scald
A	Control	196	60.5	2.0
	Thinned	253	1.6	11.5
B	Control	117	1.7	2.6
	Thinned	238	5.0	16.4
C	Control	101	16.8	0.0
	Thinned	152	16.4	14.5
D	Control	553	13.2	0.0
	Thinned	787	27.7	0.0

Note:

(a) The two species of aspen (P. tremuloides and P. grandidentata) were the only species considered.

(b) Trees examined on control plot of similar size and spacing to those on thinned plots.

The hypoxylon canker attacked from 1.6 to 27.7 per cent of the trees in the thinned stands and from 0.5 to 16.8 per cent of similar trees in the control plots. The differences in the degree of infestation between thinned and unthinned plots were tested for significance by the $(\text{Chi})^2$ test (10). The aggregate figures for all the plots were found to be significant; but when individual pairs of plots were taken, only the thinned and unthinned sections of Stand D differed appreciably. Hence, on the basis of these data, thinning cannot be said to definitely increase the incidence of canker in aspen stands.

Direct comparative data as to the proportion of infected trees which eventually die as a result of the attack are not available, but in Stand D, the most heavily infected area, 218 infected trees were noted on the thinned plot in 1940, while the mortality from all causes in the following five-year period was only 137 trees. Casual observation of all plots in 1945 tended to indicate that many of the cankers had healed over.

All of the thinned stands except Stand D suffered from sun-scald, 11 to 16 per cent of the trees being so damaged; in the unthinned plots damage from this source was less than 2 per cent. The thinned section of Stand D escaped injury, possibly because of the greater number of trees per acre left after the thinning. It is very evident that sun-scald constitutes a major problem in thinning aspen since the trees are rendered unmerchantable by this injury, or by its immediate consequences of permitting fungi to infect the tree.

The following information relative to other injuries on the plots is quoted directly from the report (7):

"In addition to Hypoxylon canker and sun-scald, the following kinds of defect were commonly encountered.

"Some defects were caused directly by the thinning operation. Some of these were axe wounds, made while removing other trees, and may be classed as strictly avoidable. Most of the "thinning" wounds, especially in the older stands, are caused by other trees being felled against the reserved trees, resulting in breaking or stripping the bark. It is probable that most of these are avoidable.

"Insect tunnels have caused blemishes on many trees, and in some cases appear to be the primary causes of more extensive injury by fungi and wind-breakage.

"Frost cracks may be small and inconsequential, or they may constitute serious defects. They are not uncommon.

"Porcupine injury was encountered on seven of the eight plots examined.

"A canker of Nectria type is common, but apparently not serious

"The presence of heart rots can be determined only when sporophores are produced after the disease has reached an advanced stage. Sporophores of Fomes igniarius were found on two trees in the thinned section of Stand C and on one tree of the unthinned section of the same stand.

"The examination of these four pairs of plots has made it clear that diseases must be taken into serious account in the thinning of poplar. It is yet too early in the present study to make detailed recommendations regarding the various diseases encountered. However, one general recommendation can be stated without hesitancy, as follows. At each thinning, in addition to the trees normally selected to remain there should be left a generous surplus of trees intended to serve as replacements for trees that may be later killed or reduced in value by diseases."

5. DISCUSSION AND RECOMMENDATIONS

The end purpose of the experiment is to reach a decision as to whether the thinned stands produced a better return from the area than the untreated stands. Such a purpose cannot be completely achieved until after the stands have been harvested, but tentative conclusions regarding the final outcome can be drawn from the foregoing analysis. From the analysis the advantages and disadvantages of the thinning operation may be summarized as follows.

Advantages	Disadvantages
(1) Diameter increment - stimulated by thinning.	(1) Diameter increment-stimulation mostly in smaller trees which may be expected to die.
(2) Height increment - not decreased.	(2) Height increment - not increased.
(3) Volume increment - per tree increment much higher than unthinned stand.	(3) Volume increment - per acre increment mostly lower or equal to unthinned stands.
(4) New growth - becomes established.	(4) New growth - mostly of species other than aspen.
(5) Mortality - greatly reduced.	(5) Mortality - unless thinnings utilized they may be considered as mortality thus making the stands about equal in this respect.
(6) Quality - larger individual trees obtained.	(6) Quality - considerable proportion of the trees damaged by sun-scald and thinning wounds.

continued

Advantages	Disadvantages
(7) Rotation - shortened since trees reached merchantability sooner.	(7) Rotation - less trees at end of rotation.
(8) Cost - occasionally an immediate profit from thinning.	(8) Cost - thinning operation usually at a loss which cannot be presently justified.

In only one stand could the advantages of thinning be said to outweigh the disadvantages. This was in stand B, which was 22 years of age at the time of treatment, and is located on the best site in the area (Aralia site-type). In this stand the diameter growth was much superior to that on control plot, the average volume increment per tree was almost three times as great, and the "useful" volume increment was slightly greater than on the control plot. Moreover, this was one of the two stands in which the thinning might have been made at a profit, since 6.5 cunits of merchantable material were available from the operation. In the other stands the thinning cannot be justified by the results to date, unless made at a profit, since the resulting stimulation of growth was not great. In stand C, the only other stand containing sufficient merchantable material to allow a profit on the thinning operation, the thinning was so severe that subsequent mortality and damage was so great as to render the thinning operation a failure. In this stand it is believed that its site and age (40 years) were major factors contributing to the excessive mortality.

From the experiment, it is the opinion of the writer that thinnings in aspen should be made <u>only</u> when the following conditions can be satisfied:

(1) Site: on best quality only. At Petawawa this will include the Aralia and Trillium site-types.

(2) Age: at about 20 to 30 years of age. At this age there will be sufficient merchantable material to permit the thinning to be made at a profit and still leave a reasonable number of large, good-quality trees on the area.

(3) Intensity of thinning: a minimum of 400 good-quality dominant and codominant trees per acre should be left, since at least 15 to 20 per cent of these trees can be expected to die or to be rendered unmerchantable by sun-scald, disease, or other injury. Such a thinning will probably remove about 40 per cent of the merchantable volume, or possibly 5 cords per acre at the age and site suggested.

For practical application a thinning satisfying the conditions mentioned above can only be made in districts where there is a large demand for aspen as pulpwood or cordwood. If such demand and conditions do not exist, it is not deemed advisable to incur any expense in thinning in an attempt to increase the yield of aspen since the resultant stimulation in growth does not appear to warrant such an expenditure. When it is possible to carry out such a thinning, a simple way of conducting the operation is to mark with a spray gun those trees which are to be left for further growth, and then cut out as much of the remainder as is economical. It is not necessary to cut down all of the unmarked trees, since the removal of the smallest trees will not stimulate the growth to any extent, and in any event these smaller trees will die from suppression in a very short period of time.

The growth of the control plots indicates that there is no cause for concern when economic or silvicultural conditions do not permit artifical thinnings to be made in aspen stands. Unlike some other species, aspen is very susceptible to mortality from competition and subsequent suppresion, with the smaller trees dying out very rapidly, thus effecting a natural thinning which, in the untreated stands studied, reduced the number of teees per acre by approximately fifty per cent in a ten-year period. Since this natural thinning process is gradual, very little of the damage from sun-scald and other injuries which accompany artifical thinning to a greater or lesser degree is likely to occur. In cases where aspen stands retain about the same number of trees per acre for any long period, it may be surmised that the site is poor and that no appreciable improvement in growth will result if the stands are thinned.

While thinning on poor quality sites cannot be justified on the basis of increased yields, it is quite possible that under certain conditions a thinning will hasten the type conversion to another species or groups of species which can make better use of the site. This problem of type conversion is beyond the scope of the present experiment, but it is interesting to note that in the stands on which coniferous reproduction is becomming established the greatest amount of coniferous growth is entering the thinned section.

6. SUMMARY

Four young aspen stands of varying age, site, and density were heavily thinned at the Petawawa Forest Experiment Station in the period from 1934 to 1936 to determine the effect of the treatment upon the growth and yield of the stands. A remeasurement of the stands made ten years after treatment indicated that although the diameter and volume growth of individual trees was stimulated by the thinning, the per acre increment and yield of the thinned plots was about the same as that for the untreated check plots. The thinned plots suffered considerable damage fron sun-scald and other injuries. The unthinned stands showed a good growth and indicated that aspen on average sites will not stagnate from lack of artifical thinning since a very rapid natural thinning takes place in them.

The tentative conclusion drawn is that the role of thinning in the management of aspen stands is very limited, and in most cases impractical. There appears to be a possibility that thinning may be silviculturally and economically practicable in young (20 to 30 years) stands occurring on the best sites, and which contain sufficient merchantable material to permit a profitable thinning to be made and still leave at least 400 good-quality dominant trees per acre. Failing such conditions, thinning in aspen stands is not recommended.

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APPENDIX A

Condition of Plots Before Treatment

	No.137	No.138	No.139	No.140	No.150	No.151	No.153	No.154
				Number of Trees per Acre				
Entire Stand	2189	2762	1379	1776	778	704	2973	2651
Stand over 9.0 inches D.B.H.	-	-	-	6	-	-	-	-
" 8.0 " "	-	-	-	15	31	36	-	-
" 7.0 " "	-	-	15	18	105	105	-	-
" 6.0 " "	-	-	72	32	205	200	-	-
" 5.0 " "	17	22	175	91	345	365	-	-
" 4.0 " "	130	130	350	191	510	500	-	-
" 3.0 " "	560	560	685	560	630	618	10	16
" 2.0 " "	1490	1490	1020	1190	735	665	560	430
" 1.0 " "	2010	2360	1285	1645	775	704	1295	1660
				Average Diameter, Inches				
Entire Stand	2.60	2.45	3.60	2.90	4.70	4.9	1.5	1.5
200 largest trees per acre	4.20	4.40	6.11	5.51	6.61	6.7	2.6	2.7
400 " " " "	3.87	4.00	5.30	4.65	5.80	5.9	2.4	2.5
				Average Height, Feet				
Entire Stand	31.6	28.6	43.1	39.9	53.3	59.8	19.3	17.0
200 largest trees per acre	42.5	42.5	59.4	56.7	63.5	72.3	27.9	27.8
400 " " " "	40.7	40.1	55.2	52.8	59.6	67.6	26.7	26.2
				Total Volume per Acre, Cubic Feet				
Entire Stand	1570	1693	2428	1938	2507	3047	511	446
200 largest trees per acre	440	490	1200	940	1435	1900	132	136
400 " " " "	720	760	1650	1370	2100	2680	230	225
				Merchantable Pulpwood, Volume per Acre, Cubic Feet				
Entire Stand	298	323	1327	910	1476	2200	2.4	6.4
200 largest trees per acre	240	255	950	720	1190	1510	2.4	6.4
400 " " " "	298	323	1285	910	1685	2100	2.4	6.4
				Stand Density Index				
	256	304	266	245	232	224	140	124
				Percentage Composition				
Large-toothed Aspen	93	65	20	42	7	8	1	T*
Trembling Aspen	2	25	46	11	70	81	99	100
White Birch	1	-	15	19	12	7	-	-
Red Oak	4	5	3	7	-	-	-	-
Red Maple	-	7	16	21	6	4	T	-
Basswood	-	-	T	T	1	-	-	-
Ash	-	-	T	-	1	-	-	-
White Pine	-	-	-	-	T	-	-	-
Red Pine	-	-	-	-	T	-	-	-
Balsam Fir	-	-	-	-	1	-	-	-
Spruce	-	-	-	-	2	T	-	-

*"T" Signifies less than one per cent

Thinned Plots - Before and After Thinning

	No.137			No.139			No.150			No.154		
	Original	Per-centage Removed	Residual	Original	Per-centage Removed	Residual	Original	Per-centage Removed	Residual	Original	Per-centage Removed	Residual
					Number of Trees per Acre							
D.B.H. Class, Inches												
1.0	298	100	0	113	100	0	40	80	8	1690	86	225
2.0	892	96	39	408	99	4	104	94	6	836	45	457
3.0	687	69	212	350	91	32	125	95	6	121	16	102
4.0	274	43	155	259	69	79	164	86	23	4	-	4
5.0	35	49	18	126	41	72	138	68	44	-	-	-
6.0	3	-	3	91	37	57	101	50	51	-	-	-
7.0	-	-	-	25	32	17	75	32	51	-	-	-
8.0	-	-	-	2	50	1	30	27	22	-	-	-
9.0	-	-	-	-	-	-	1	-	1	-	-	-
10.0+	-	-	-	5	80	1	-	-	-	-	-	-
Entire Stand	2189	81	427	1379	81	263	778	73	212	2651	70	788
					Average Diameter, Inches							
Entire Stand	2.6		3.4	3.6		4.2	4.7		5.9	1.5		1.9
200 largest trees per acre	4.2		3.9	6.1		5.6	6.6		6.0	2.7		2.7
400 " " " "	3.9		3.5	5.3		5.0	5.8		-	2.5		2.4
					Average Height, Feet							
Entire Stand	31.6		38.0	43.1		48.0	53.3		60.0	17.0		21.0
200 largest trees per acre	42.5		40.9	59.4		55.8	63.5		60.8	27.8		27.8
400 " " " "	40.7		38.0	55.2		53.6	59.6		-	26.2		25.4
					Total Volume per Acre, Cubic Feet							
Entire Stand	1570	63	573	2428	60	959	2507	53	1177	446	46	244
200 largest trees per acre	440	14	380	1200	26	880	1435	17	1180	136	4	130
400 " " " "	720	24	550	1650	42	959	2100		-	225	10	196
					Merchantable Pulpwood, Volume per Acre, Cubic Feet							
Entire Stand	298	42	172	1327	49	676	1746	45	955	6	-	6
200 largest trees per acre	240	28	172	950	30	668	1190	20	950	6	-	6
400 " " " "	298	42	172	1285	47	676	1685		-	6	-	6
					Stand Density Index							
	256		76	266		65	232		91	124		54
					Percentage Composition							
Large-toothed Aspen	93		95	20		24	7		5	1		T*
Trembling Aspen	2		4	46		67	70		85	99		100
White Birch	1		1	15		7	12		1	-		-
Red Oak	4		-	3		1	-		-	-		-
Red Maple	-		-	16		1	6		-	T		-
Basswood	-		-	T		-	1		-	-		-
Ash	-		-	T		-	1		-	-		-
White Pine	-		-	-		-	T		T	-		-
Red Pine	-		-	-		-	T		T	-		-
Balsam Fir	-		-	-		-	1		1	-		-
Spruce	-		-	-		-	2		8	-		-

*"T" Signifies less than one per cent

CHART 1
AVERAGE DIAMETER
of 200 LARGEST TREES per ACRE

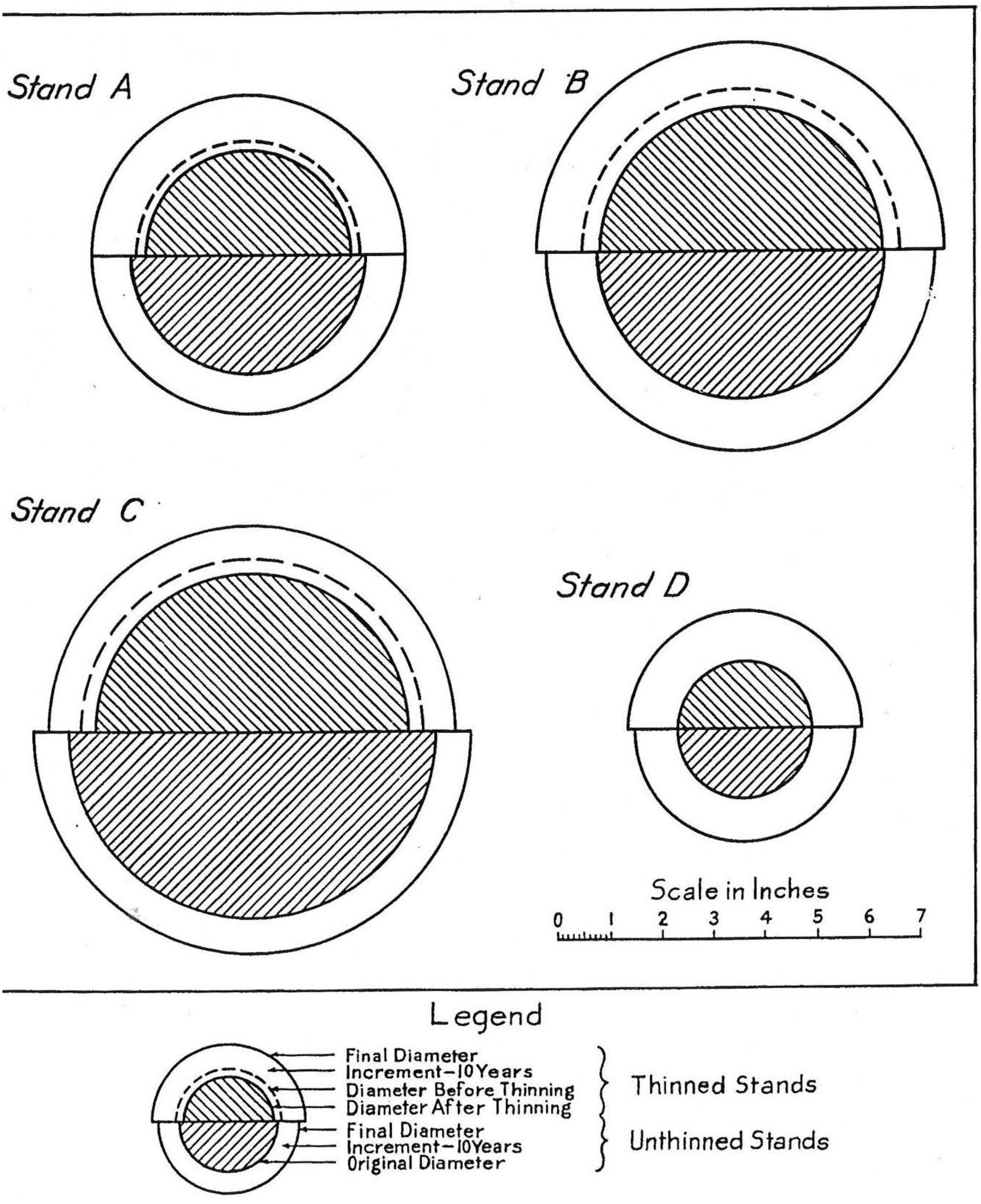

CHART 2

DIAMETER - HEIGHT CURVES

Aspen

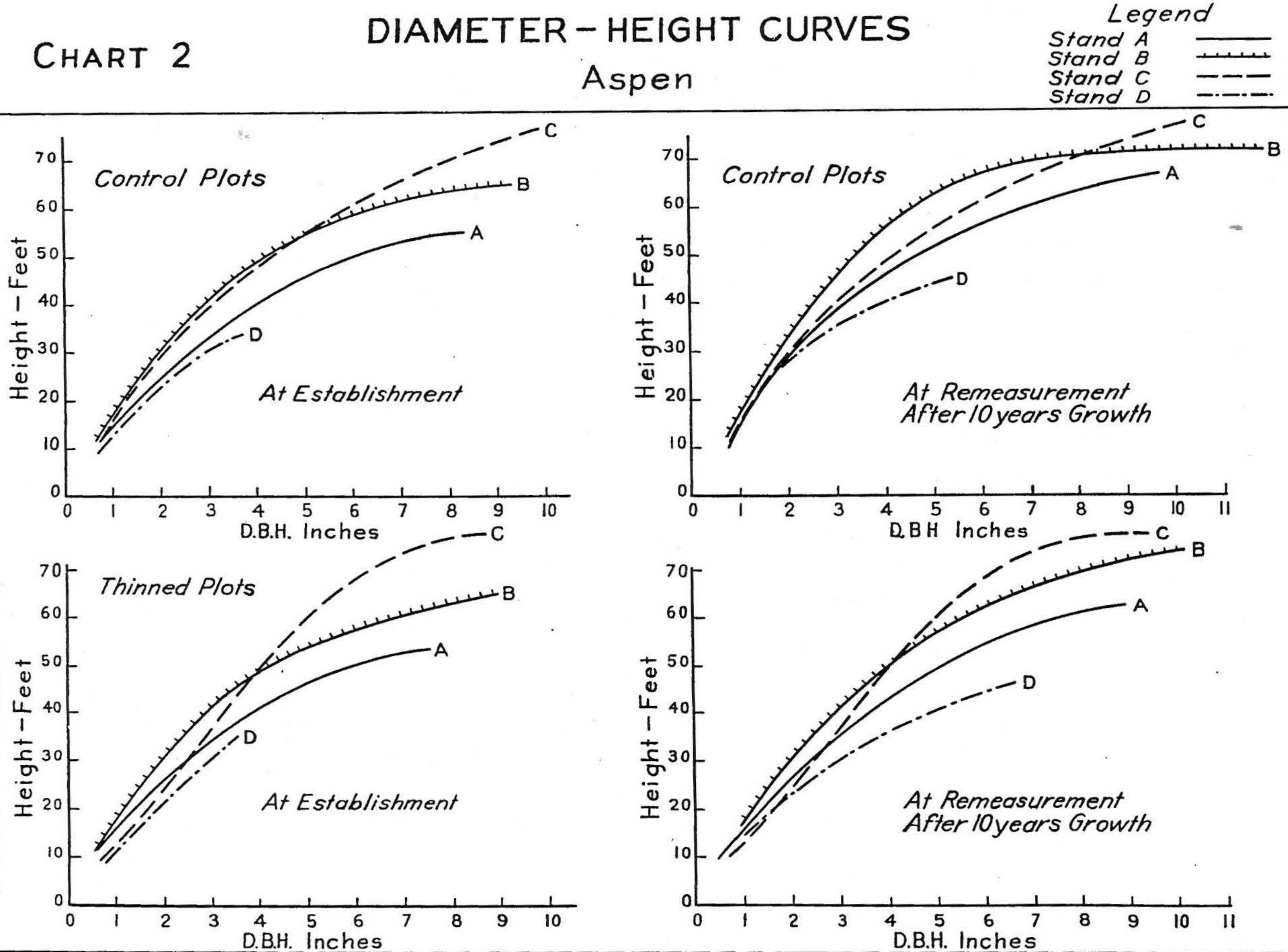

CHART 3

GROSS INCREMENT of ASPEN – TOTAL CUBIC FEET
for TEN YEAR PERIOD AFTER THINNING
Per Tree and Per Acre